Ancient regulation in the field of concrete structures design

Ricardo José Coelho Barbosa

ri.cardo7@hotmail.com

Supervisor:

António José Da Silva Costa

acosta@civil.ist.utl.pt

Abstract

In spite of the great predominance of new buildings, this type of construction has been losing its absolute importance in the construction sector; in contrast, the rehabilitation of buildings is an increasing investment in the sector and currently accounts for a third of activity. In the context of rehabilitation an important aspect is to provide buildings with the safety levels considered in the current regulation.

The assessment of differences in the design of structures, in the comparison of old regulations with existing regulations, is extremely important in order to understand the main structural weaknesses in constructions prior to the date of publication of the regulations in question. The intervention in existing buildings presupposes a structural evaluation antecedent to the intervention in the building. The objective of the study is to evaluate the regulations that framed the project of existing buildings at different times, comparing it with the current regulations, in order to perceive the evolution of the regulation in terms of the consideration of actions, the capacity to resist the various forces and detailing.

In the first phase an analysis of the evolution of the old regulation was carried out, both in the field of actions and in the field of structural design. The comparison of the different regulations in terms of technological evolution, introduction of new theoretical concepts and perception of the variation of the resistant capacity of the structures to the various forces allows to obtain a holistic view on the deficiencies that can come from the design through old regulation. In a second phase, an analysis is carried out on old building projects, through a structure characterization, analysis of the project actions and methodology for calculating and evaluating the details of

reinforcements, typifying a set of possible structural problems considering the current regulations regarding time of designing the building.

Through the analysis of the regulations and the old designs, there is an evolution of the provisions regarding the detailing of reinforcements in vertical and horizontal elements and their connection, the increase in the amount of transversal reinforcement, the verification of the safety to punching and the quality of presentation of project elements.

Key-words: Rehabilitation, Structural problems, Ancient regulation, Structural design, Regulation evolution

1. Introduction

The perception of the evolution of regulation and its application in the analysis of old buildings projects is of the utmost importance, since it allows to obtain a holistic vision about structural design, the properties of the materials, construction techniques, safety verification to the various forces and the structural behavior itself according to the current regulation, indispensable aspects in the assessment of a building to be rehabilitated.

The economic benefits of rehabilitation compared to demolition and rebuilding translate a significant reduction in demolition costs, construction site costs, licensing costs and fees, reduction of urban traffic disturbances and reduction of quantities of new materials. It turns out that the total cost of rehabilitation work may be lower compared to the construction of a new building, even if unit prices for rehabilitation works are higher. The need to conserve a significant part of the constructed elements is relevant, since in comparison with the new construction it translates into the reduction of energy consumption in the production and application of construction products, eliminates part of the CO2 emission and reduces the products of demolition to remove and destroy [1].

The regulation comes as a synthesis document and its implementation results from innovations and technological development, asserting itself as a guarantee of quality in construction, satisfying the requirements of appropriate behavior in order to verify the safety of people and goods. Due to the great importance in Portugal of the use of reinforced concrete in the twentieth century, the need arose to create the first Portuguese regulation, and until then the works in dependence of the public administration were inspected according to instructions annexed to the French ministerial circular of October 20, 1906 [2].

The Portuguese Army presents an extensive and important built heritage, and a high percentage of buildings had different occupations over time. The assignment of new functions to army buildings is an indispensable mechanism, since constant adaptation due to economic, social, political and defense reasons is a determining factor for the full accomplishment of its mission. The Lei de Infraestruturas Militares (LIM) (Organic Law No. 6/2015, of May 18) aims to plan the investment taking into account the maintenance, modernization, conservation and construction of the fixed component of the system of forces, which results in the profitability of the infrastructures affected by the Armed Forces of which the Portuguese Army is an integral part. The need to modernize and monitoring infrastructures is now one of the main priorities for military and political leaders [3–5].

2. Ancient regulation in the field of actions

2.1. Live loads

The theory of reinforced concrete structures has been updated since the beginning of the 20th century, and it is natural that evolution develops as each regulation is introduced, although the changes about gravitational actions are not significant. However, there are some refinements and innovations resulting from the technological evolution associated with the construction [6].

As can be seen in Table 1, the values of the live loads did not change significantly since the assignments of numerical values to the live loads take into account the nature of the phenomena that originate them, however the investigation developed on the subject allowed small improvements as regulations were updated.

Table 1: Comparison of the values of the live loads (adapted) from [7, 8].

Types of use	RBA (1935)	RSEP (1961)	RSA (1983)
Houses	200 kg/m^2	200 kg/m^2	200 kg/m^2
Offices	300 kg/m^2	300 kg/m^2	300 kg/m^2
Public buildings	400 kg/m^2	300 / 400 kg/m^2	300 / 400 kg/m^2
Show rooms	500 kg/m^2	500 / 600 kg/m^2	500 / 600 kg/m^2
Public garages	600 kg/m^2	600 kg/m^2	500 kg/m^2

2.2. Seismic action

Seismic design and construction technologies have undergone developments over time. The first Portuguese regulation to explicitly consider the seismic action was the RSCCS (Regulamento de Segurança das Construções contra os Sismos), approved by the Ministry of Public Works in May 1958. The strong seismicity of the country together with the perception at the time of the importance of guaranteeing a high degree of safety of the population, as well as the negative economic impact related to the collapse of structures during an earthquake, were the reason to develop a specific document on the design of structures to resist the seismic action

The evolution of seismic zoning has undergone significant changes throughout the various regulations. Figure 1 shows the continental Portugal seismic zoning of the 1958, 1961 and 1983 regulations, as well as the division included in the national annex of EC8.

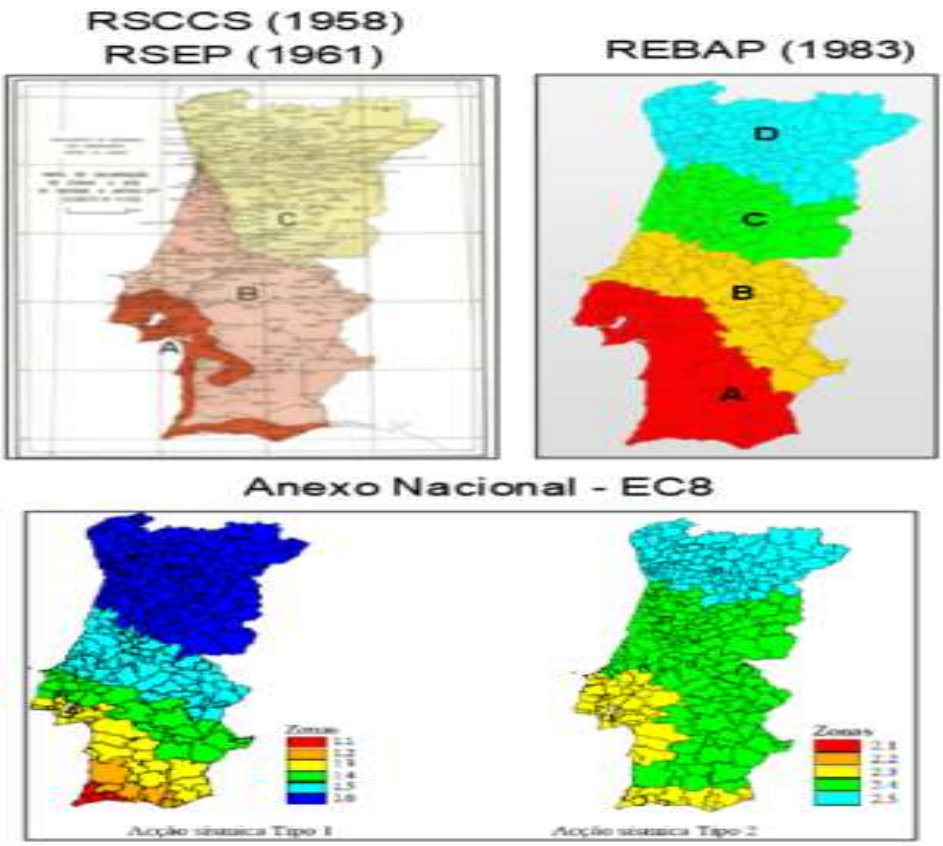

Figure 1 – Evolution of seismic action zoning in Portugal (adapted) from [2].

By analyzing the evolution of the regulations, it can be seen that the seismic action provisions did not change significantly until the current RSA regulation (1983), where there is an update of the intensity of the seismic action and the increase in the rigor required in the modeling of the effects of the earthquake on the structure, particularly with the introduction of dynamic analysis methods. The EC8 introduces a new review of the intensity of the seismic action and its variation throughout the country and again raises the rigor required for the modeling of the effects of the seismic action with dynamic and static linear and non-linear analysis models

3. Ancient regulation in the field of concrete structures design

3.1. Materials: Steel and Concrete

Regarding the materials, there is an evolution of the properties of the materials, highlighting the increase of the resistance class of the concrete and the transition from the use of smooth bars to ribbed bars. Until 1967 for concrete was designated a dosage type, thereafter the concrete is organized into resistance classes. The transition from the use of smooth bars to ribbed bars occurs with the REBA in 1967. The use of smooth bars presents a lower bond when compared to the ribbed bars, so this aspect has implications for the efficiency in the cracking control and the length of anchorage, allowing in the use of the ribbed steel, a greater effectiveness in the control of crack openings, as well as the reduction of required anchorage length. Table 2 shows the evolution of the concrete characteristics considered in the different regulations.

Table 2 - Comparative analysis of the evolution of concrete characteristics.

Regulation of 1918	Dosage prescribed in the regulation (300kg of cement, 400 liters of sand, 800 liters of gravel) There is no concept of resistance class	Mean resistance value over 120 kg/cm^2, through cubes, at 28 days
RBA (1935)	Dosage prescribed in the regulation (300kg of cement, 400 liters of sand, 800 liters of gravel) There is no concept of resistance class	Mean resistance value over 180 kg/cm^2, through cubes, at 28 days
REBA (1967) **RBLH (1971)**	B180, B225, B300, B350 and B400 2 types of concrete: B for resistance requirement and BD 1,2,3 for special durability requirement	Characteristic resistance in kg/cm^2, through cubes, at 28 days
REBAP (1983)	B15 to B55, with the resistance increasing by 5 MPa to each class Classes defined in international units (MPa)	Characteristic strength in MPa, through cubic test pieces
EC2 (2010)	2 types of concrete: normal concrete and light concrete Classes of resistance increased to C90 / 105	Characteristic resistance in MPa, through cubic and cylindrical test pieces

3.2. Safety check models

The study of the evolution of the models of analysis and design demonstrates that there are no constraints that compromise the safety of structures scaled through previous regulations to the current ones, in spite of a change in the safety philosophy from 1967. In Table 3 can be analyzed the evolution of analysis models and safety philosophies.

Table 3 - Evolution of analysis models and safety philosophies

Regulation of 1918	Safety check made by the criterion of allowable stress	Calculation of stresses based on a linear elastic model
RBA (1935)	Safety check made by the criterion of allowable stress	Calculation of stresses based on a linear elastic model
REBA (1967)	Safety check by limit states	Concepts of non-linear analysis and plastic calculation
REBAP (1983)	Improvement of safety check by limit states	Elastic and linear analysis, non-linear analysis and plastic calculation
EC2 (2010)	Increased safety-related complexity	Elastic and linear analysis, non-linear analysis and plastic calculation

3.3. Bending moment

When comparing through the resistant calculation capacity M_{rd}, regulations with the same philosophy of safety verification, such as REBA, REBAP and NP EN1992-1-1, there is a small difference when the percentage of reinforcement is greater than 2,5%, as can be seen in Figure 2. The differences may result from aspects such as the shape of the stress-strain diagram and the limitation of the maximum deformation of the concrete, but also because the design strength, f_{cd}, is effected as $0{,}85(f_{ck}/1{,}5)$, in the case of REBAP and for NP EN1992-1-1 may be given by $1{,}0(f_{ck}/1{,}5)$. It should be noted that in relation to bending moment stress, when analyzing the different regulations, including the 1918 and 1935 regulations, there is no significant change in the resistant capacity of the reinforced concrete elements taking into account current regulations [2, 6, 9, 10].

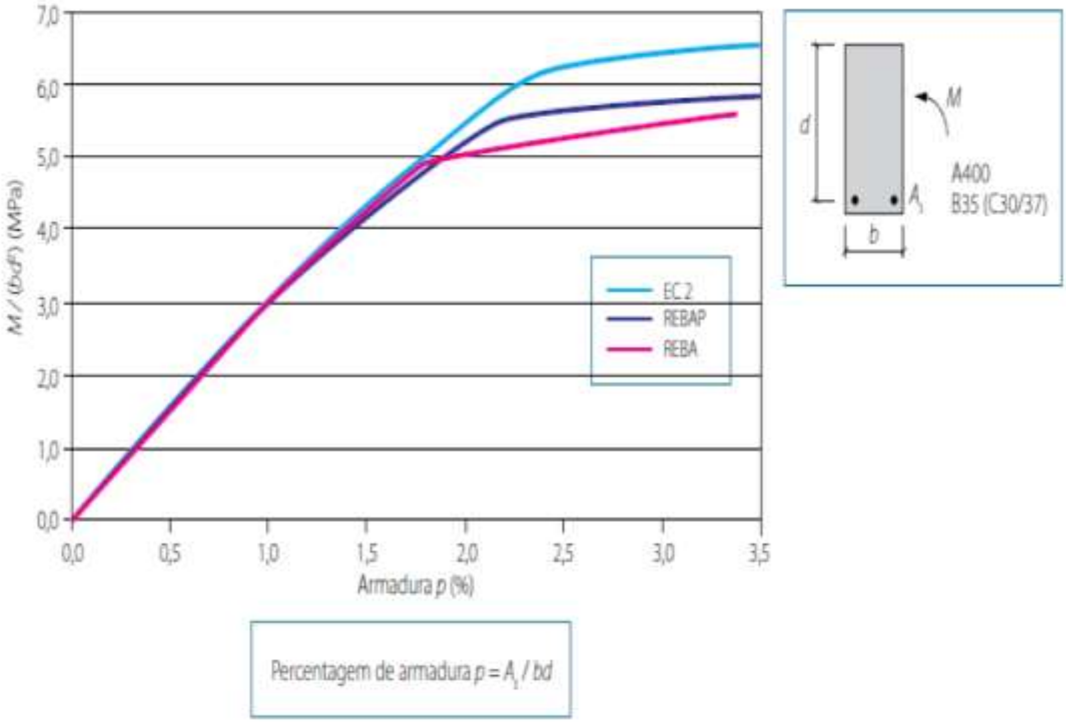

Figure 2 - Comparative analysis of the simple flexural strength of REBA (1967), REBAP (1983) and EC2 (2010) [2].

3.4. Shear

The analysis of shear force was performed independently for elements without transverse reinforcement and for elements with transverse reinforcement. For elements without transverse reinforcement with the entry of the REBA there is a significant increase of the capacity resistant to the transverse force, being reduced again with the entry into force of the REBAP, and later with the EC2 as can be observed in Figure 3.

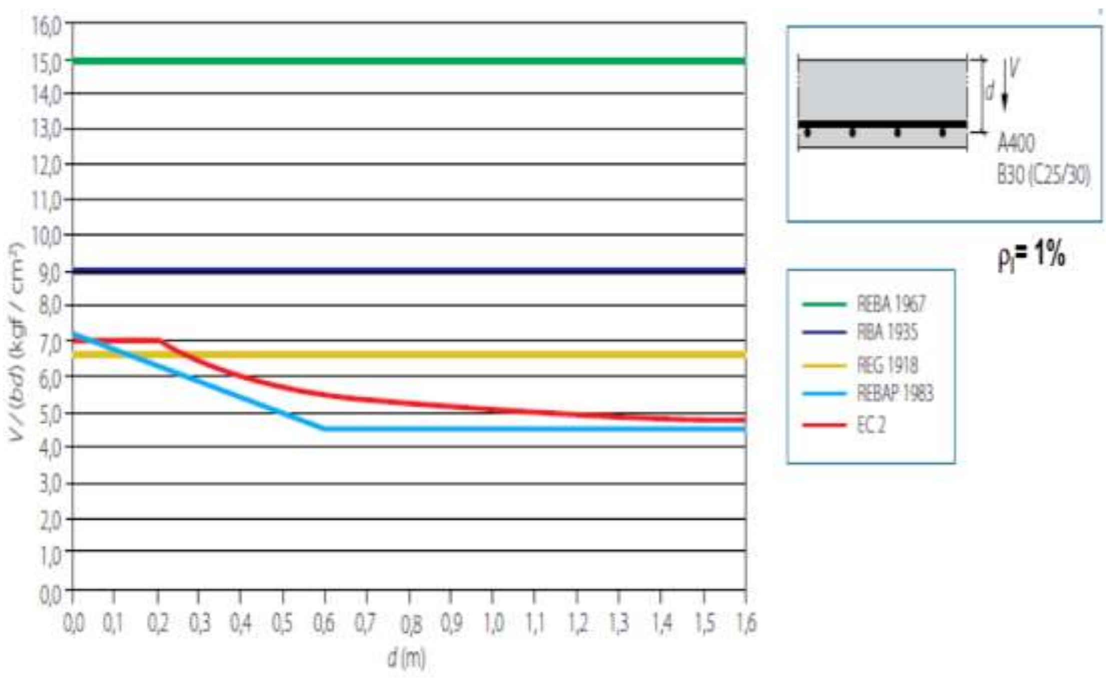

Figure 3 - Comparative analysis of resistance to transverse stress of elements without transverse reinforcement [2].

In elements with transverse reinforcement and comparing the resistant capacity to shear force, it can be seen that there are no significant differences in the shear strength of the various regulations as can be seen on Figure 4.

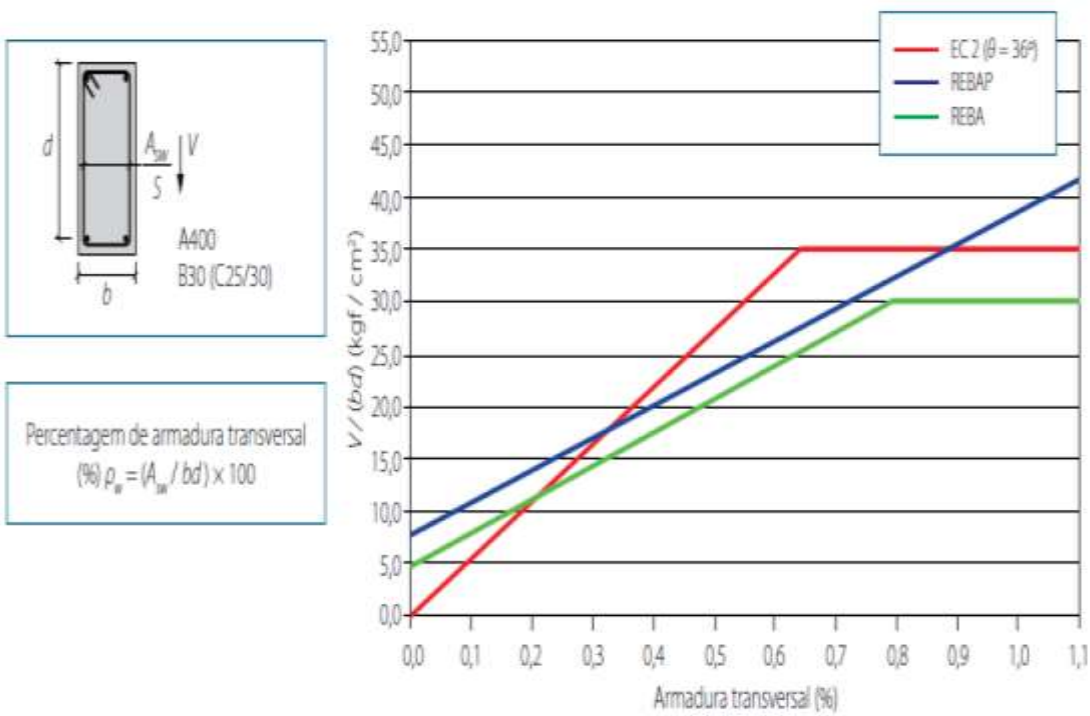

Figure 4 - Comparative analysis of resistance to transverse stress of elements with transverse reinforcement [2].

3.5. Bending and axial force interaction

In the particular case of the design of structural elements subject to bending and axial force interaction the criterion of resistance is dependent of two forces simultaneously. Comparing the two regulations (REBA and EC2) it´s observed that the difference results from the strain limitation of the most compressed fiber to 2 ‰ in the REBA where as in the EC2 this is limited to 3.5 ‰. However, the most significant difference is evident when comparing EC2 and REBAP, more properly, in a higher compressive strength, result of the concrete strength obtained by $0{,}85f_{cd}$ in the case of REBAP and $1{,}0f_{cd}$ in the case of EC2. Figure 5 demonstrates a comparative analysis of the resistant capacity to the bending and axial force interaction forces between REBA, REBAP and EC2. In general, it can be stated that the differences found do not affect the safety of the concrete members dimensioned for this type of stress [2, 11].

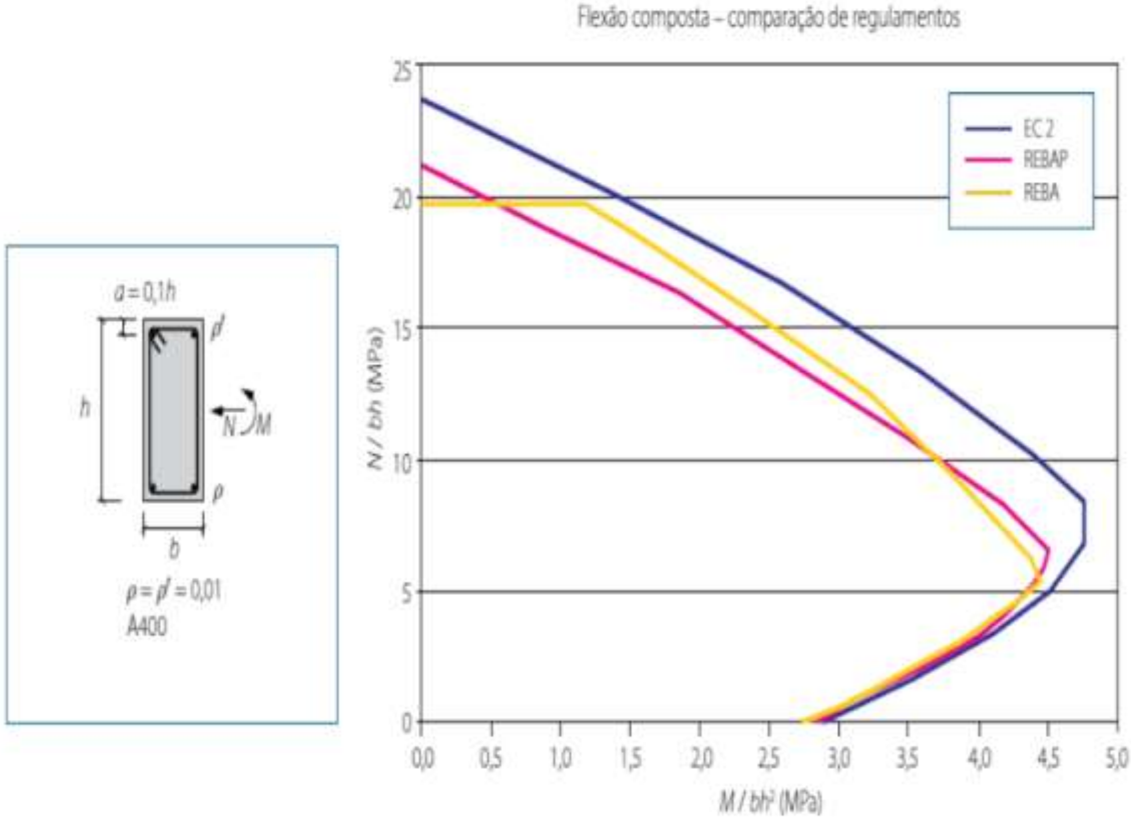

Figure 5 - Comparative analysis of resistant capacity due to flexural and shear interaction [2]

4. Analysis of old projects

A summary of the main structural deficiencies is given in Table 4, considering the prevailing epochs of the 1918, 1935, 1967 regulations. It should be noted that most of the constructions carried out before 1983 present some problems in their majority regarding detail and quantity of reinforcing steel which together with the fact that the seismic action has undergone significant changes throughout the regulations can cause problems in the structural safety [2].

Table 4 - Summary of structural problems by season

Regulation	Structural Problems
Regulation of 1918	• Use of smooth bars implies a lower bond when compared to ribbed reinforcement, which translates into less effective splinting control as well as longer anchorage length. • Low transversal reinforcement • Low anchorage length at the end supports • Design and location of expansion joints unsuitable for resistance to seismic action
RBA (1935)	• Low anchorage length at the end supports • Low longitudinal reinforcement at end supports • Low transversal reinforcement • Adoption of inclined bars for resistance to shear force can present a bad behavior to the seismic action • Robust beams supported by weak columns can give rise to flexible floor mechanisms due to seismic action • The transverse reinforcement of the columns is generally low which can lead to premature rupture • Expansion joint not dimensioned for seismic action may not accommodate seismic displacements • Low anchorage on beam-column connection • In general, there is no extension of the transversal reinforcement to the interior of the beam-column node
REBA (1967)	• Punching problems in buildings with flat slabs • Shear resistance of elements without transverse reinforcements overestimated

5. Conclusions

Understanding the evolution of regulation and its application in the analysis of older design method is of the utmost importance as it provides an overall view of structural design, material properties, construction techniques, multi-effort safety checking and structural behavior itself in light of current regulations, indispensable aspects in the assessment of a building to rehabilitate.

This investigation allowed the identification of structural deficiencies related to actions and structural design. The results show that in constructions carried out before 1983, there are several provisions concerning the detailing of reinforcement that can result in structural problems when an earthquake occurs. The transversal reinforcement of the columns is generally insufficient and can cause a permanent rupture of the section by transverse forces. In addition, there is also a low anchorage length of the columns in the beams as well as a low longitudinal reinforcement in the vertical elements which can confer low robustness of the columns for seismic action. In beams, the lower reinforcement at the end supports is generally insufficient due to disregard for seismic action. The transversal reinforcement is generally reduced and rely on the adoption of inclined bars that present a bad behavior in case of inversion of forces. Existing stirrups are generally insufficient to ensure the plastic behavior of the elements with the necessary ductility. Whether on beams or pillars, the interruption of the longitudinal reinforcement is generally deficient.

References

[1] J. Appleton, “Jornadas da Especialização em Direção e Gestão da Construção - Reabilitação de Edifícios: princípios e práticas,” 2014.

[2] J. Appleton, *Estruturas de Betão*, 1ª Edição. Lisboa, 2013.

[3] D. Fiott, “Modernising NATO’ s Defence Infrastructure with EU Funds,” *Surviv. Glob. Polit. Strateg.*, vol. 6338, 2016.

[4] C. S. Lobão, C. S. Pires, and C. (BRZ) R. Menezes, “O processo de financiamento das infraestruturas das Forças Armadas. Uma visão prospetiva.,” Pedrouços, 2016.

[5] C. Correia, “Intervenção no Prédio Militar N. º 50, em Lisboa, antiga Fundição de Canhões,” Instituto Superior Técnico, 2015.

[6] J. Appleton, “Eurocódigo 2 - EN1992-1-1,” Lisboa, 2004.

[7] A. Costa, “Apontamentos da disciplina Reabilitação e Reforço de Estruturas - Avaliação de Estruturas Existentes.” Instituto Superior Técnico, Lisboa, 2018.

[8] “Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings,” vol. 1, no. 2004, 2011.

[9] J. Sena-cruz and P. Lourenco, “Flexão simples: análise comparativa REBAP vs EC2,” no. January 2006, 2018.

[10] E. Pereira and J. Sena-cruz, “Flexão composta: análise comparativa REBAP vs EC2,” 2008.